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THE FUNDAMENTALS OF THE MEASUREMENT OF THE DOSIMETRIC QUANTITIES IN HADRONTHERAPY

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Abstract – The most important quantity for the dosimetry in radiotherapy is the absorbed dose in water.

The calibration of the measuring instruments for D_w is a current operation when these instruments are dedicated to the measurement of this quantity for photon radiation.

In the last years, a new type of particle beams began to be used in the radiotherapy: the hadrons.

For hadrons, the measurement of the absorbed dose has still unsolved aspects which are the abject of the research in many laboratories. The calibration of the measuring instruments for D_w in hadron beam is also the subject of many research projects. This paper deals with the fundamentals of the measurement and calibration for D_w in hadron beams, for radiotherapy.

Keywords: hadrontherapy, dosimetry, ionizing radiation

1. INTRODUCTION

In the last years, a new challenge appeared for the radiation measurement in radiotherapy: the hadron therapy, which means the use of the hadrons beams (protons, hellions, C^{12} ions) in the new radiotherapy techniques.

The physical quantity of interes in radiotherapy, generally, is the absorbed dose to tissue. For the moment, the human tissues are still simulated by water, due to the high concentration of water in the human body. The dosimetry of hadrons beams for use in the cancer therapy is a quite new field of the absorbed dose measurement.

For the measurement of the absorbed dose in human tissues, the present research has two aims:

- the development of existing measurement systems, in order to make them adequate to the hadrons measurement;
- the development of new detectors and measurement systems, specially designed for this type of ionizing radiation.

2. THE ABSORBED DOSE IN HADRON BEAMS

A typical depth-dose distribution for a therapeutic proton beam is shown in Fig.1

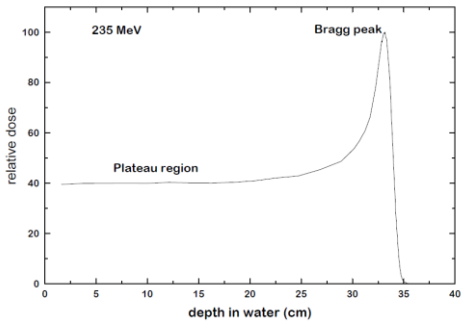

Fig. 1
Percentage depth-dose distribution for a 235 MeV proton beam, illustrating the "plateau" region and the Bragg peak.

This consists of a region where the dose increases slowly with depth, called the "plateau", and a region where the dose rises rapidly to a maximum, called the "Bragg peak". Clinical applications require a relative uniform dose to be delivered to the volume to be treated and, for this purpose, the proton beam has to be spread out both laterally and in depth. This is obtained at a treatment depth by the superposition of Bragg peaks of different intensities and energies. The technique is called "beam modulation" and creates a region of high dose uniformity, referred to as the "spread-out Bragg peak" (SOBP).

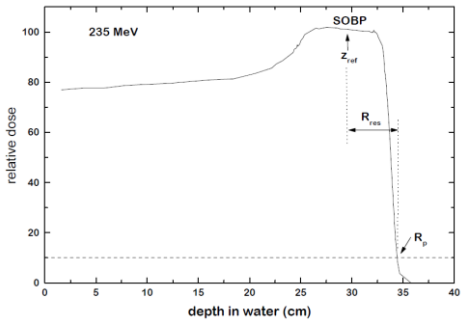

Fig.2
Percentage depth-dose distribution for a modulated proton beam.

The width of the SOBP is normally defined by the width of the 95% dose levels. spreading out of a Bragg peak can be achieved by different modulation techniques such as energy modulation [2], or raster scanning or dynamic spot scanning [2], [3].

3. DOSIMETRY EQUIPMENT

Clinical proton dosimetry to date has been based on different types of dosimeters, such as calorimeters, ionization chamber, Faraday cups, activation systems and diodes [3], [4], [5]

Existing proton dosimetry protocols [6], [7], [8] provide recommendations for ionization chamber dosimetry, based on in-air calibrations in a ^{60}Co beam in terms of exposure and air kerma. But, the newest ICRU Report Nr. 59 [9] discusses, in addition, the determination of absorbed dose in a proton beam using ionization chamber calibrated in a ^{60}Co beam in terms of absorbed dose to water.

For clinical measurement of absorbed dose in proton beams, both cylindrical and plane-parallel ionization chamber are recommended for use as reference instruments, mainly for the calibration of the clinical beams.

Graphite walled cylindrical chambers are preferable to plastic walled chambers, because their better long term stability and smaller chamber-to chamber variations.

4. PHANTOMS AND CHAMBER SLEEVERS

Water is still recommended as the reference medium for the determination of absorbed dose and for beam quality measurements with proton beams. The phantom should extend to at least 5 cm beyond all four sides of the field size employed at the depth of measurement and also extend to at least 5 cm beyond the maximum depth of measurement.

In horizontal beams, the window of the phantom should be made of plastic and thickness t_{win} between 0.2 cm and 0.5 cm. The water-equivalent thickness (in g.cm^{-2}) of the phantom window should be taken into account when evaluating the depth at which the chamber is to be positioned; the thickness is calculated as the product $t_{win}\rho_{pl}$; is the mass density of the plastic (in g.cm^{-2}). For commonly used plastics, PMMA and clear polystyrene, the nominal values ρ_{PMMA} = 1.19 g.cm^{-3} and $\rho_{polystyrene}$ =1.06 g.cm^{-3} [9] may be used for the calculation of the water-equivalent thickness of the windows.

For non-waterproof chambers, a waterproof sleeve should be used; it is made of PMMA and, preferably, should be no thicker than 1.0 mm. The air gap between the chamber wall and the waterproofing sleeve should be sufficient (0.1 mm to 0.3 mm) to allow to air pressure in the chamber to equilibrate. The same waterproofing sleeve that was used for calibration of the user's ionization chamber should also be used for reference dosimetry. If it is not possible to use the same waterproofing sleeve that was used during calibration at the standardizing laboratory, then another sleeve of the same material and similar thickness should be used. Plane-parallel chamber, if non inherently waterproof cover, must be used in a waterproof enclosure, preferably of PMMA or a material that closely matches the chamber walls; ideally, they should be no more than 1 mm of added material in front of and behind the cavity volume.

Water column system for highest precision peak detector in proton and heavy ion therapy (PEAKFINDER).

The PEAKFINDER water column is especially designed for highest precision peak detection of proton and heavy ion beam in particle therapy. It is a closed water column for scans up to 35 cm depth with increments of 10 µm (Fig. 3).

Fig.3

Because of its sealed construction, it can used in any spatial orientation. Windows allow a visible inspection of the column inside. The signals of the built-in thin window Bragg peak chamber T34080 and the monitor chamber T34082 are read out by a TANDEM electrometer [10]

THE ABSORBED DOSE FOR PROTONS

In order to use a measuring instrument which was calibrated in reference conditions (at ^{60}Co gamma ray) for measuring the absorbed dose for protons, a correction for the radiation quality of the beam, $h_{Q,Qo}$, must be done.

The absorbed dose to water at a reference depth $Z_{ref.}$ in water for a reference beam of quality Q_0 and in the absence of the ionization chamber is given by:

$$D_{w,Q_0} = M_{Q_0} \cdot N_{D,w,Q_0} \qquad (1)$$

where M_{Q_0} is the reading of the dosimeter under the reference conditions used in the standard laboratory and N_{D,w,Q_0} is the calibration factor in terms of absorbed dose to water of the dosimeter, obtained from a standard laboratory. In most clinical situations, the measurement conditions do not match the reference conditions used in the standard laboratory. This may affect the response of the dosimeter and it is then necessary to differentiate between the reference conditions used in the standard laboratory and the clinical measurement conditions.

REFERENCE CONDITIONS

The calibration for an ionization chamber irradiated under reference conditions is the ratio of the conventionally true value of the quantity to be measured to the indicated value. Reference conditions are described by a set of values of influence quantities for witch the calibration factor is valid without further correction factors. The reference conditions for calibration in terms of absorbed dose to water are, for example, the geometrical arrangement (distance and depth), the field size, the material and the dimensions of the irradiated phantom and the ambient temperature, pressure and relative humidity. (This is equivalent to the requirement that the correction factors have the value 1).

INFLUENCE QUANTITIES

Influence quantities are defined as quantities that are not the subject of the measurement, but yet influence the quantity under measurement. They may be of different nature, as for example, pressure, temperature, polarization voltage; they may arise from the dosimeter (e.g. ageing, zero draft, warm-up); or may be quantities related to the radiation field (e.g. beam quality, dose rate, field size, depth in a phantom).

Correction for the radiation quality of the beam, h_{Q,Q_0}

When a dosimeter is used in a radiation beam of quality Q, different from that used in its calibration, Q_0, the dose to water in given by:

$$D_{w,q} = M_q N_{D,w,Q0}\, k_{q,q0} \qquad (2)$$

When the factor k_{q,q_0} corrects for the effects of the difference between the reference beam quality Q_0 and the actual user radiation quality, and the dosimeter reading M_q has been corrected from the reference value the influence quantities, other than the beam quality, from which the calibration factor is valid.

The radiation beam correction factor k_{q,q_0} is defined as the ratio, at the qualities Q and Q_0, of the calibration factors in terms of absorbed dose to water of the ionization chamber:

$$k_{q,q_0} = \frac{N_{D,w,q}}{N_{D,w,Q_0}} = \frac{D_{w,Q}/M_Q}{D_{w,Q_0}/M_{Q_0}} \qquad (3)$$

The most common the reference quality Q_0 used for the calibration of ionization chamber is Co-60 gamma radiation, in which case the symbol k_Q is used in this paper for the quality beam correction factor.

Determination of proton absorbed dose under reference conditions.

The absorbed dose to water at the reference depth Z_{ref} in water, in a proton beam of quality Q and the absence of the chamber is given by:

$$D_{w,Q} = M_Q N_{D,W,Q_0} k_{Q,Q_0}\,, \qquad (5)$$

where M_Q is the reading of the dosimeter with the reference point of the chamber positioned at Z_{ref} in accordance with the reference conditions, corrected for the influence quantities air pressure and temperature, electrometer calibration, polarity effect and ion recombination. N_{D,w,Q_0} is the calibration factor in terms of absorbed dose to water for the dosimeter at the reference quality Q_0, and h_{Q,Q_0} is a chamber-specific factor corrects for differences between the reference beam quality Q_0 and the actual quality being used, Q.

CONCLUSIONS

The paper deals with an important aspect of the dose measurement in the radiotherapy with hadrons, mainly with proton beams. A brief review of the measurement methods is given. The main point of the paper is to present the basic principle used for the calibration of the measuring devices for proton therapy, taking into account the fact that there are no reference conditions for proton beams. So, the calibration must be performed in 1,25 MeV gamma-ray, and then, appropriate correction factors must be used for protons, according the quality of the radiation beam.

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